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SHOCK INITIATION EXPERIMENTS ON THE LLM-105 EXPLOSIVE RX-55-AA AT 25°C AND 150°C WITH IGNITION AND GROWTH MODELING

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Abstract. Shock initiation experiments on the LLM-105 based explosive RX-55-AA (95% LLM-105, 5% Viton by weight) were performed at 25°C and 150°C to obtain in-situ pressure gauge data, run-distance-to-detonation thresholds, and Ignition and Growth modeling parameters. A 101 mm diameter propellant driven gas gun was utilized to initiate the explosive sample with manganin piezoresistive pressure gauge packages placed between sample slices. The run-distance-to-detonation points on the Pop-plot for these experiments showed agreement at 25°C with previously published data on a similar LLM-105 based formulation RX-55-AB as well as a slight sensitivity increase at elevated temperature (150°C) as expected. Ignition and Growth modeling parameters were obtained with a reasonable fit to the experimental data.

Keywords: Explosive, LLM-105, RX-55, shock to detonation transition, ignition and growth
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INTRODUCTION

Shock sensitivity data of new explosive formulation is desired to determine the relative safety. The explosive RX-55, based on relatively new synthesized explosive molecule LLM-105 [1], has been studied on a relatively limited basis [1-6]. It was earlier found to have a shock sensitivity between HMX and TATB based explosives in the formulation RX-55-AB (92.4% LLM-105 and 7.6% Kel-F by weight). This paper will detail recent shock initiation results on the LLM-105 based formulation RX-55-AA (95% LLM-105 and 5% Viton A by weight) by providing run-distance-to-detonation data, in-situ pressure gauge records, and Ignition and Growth modeling results and fits to the data.

EXPERIMENTAL PROCEDURE

Shock initiation experiments were performed on the LLM-105 based explosive RX-55-AA using the 101 mm diameter propellant driven gas gun at Lawrence Livermore National Laboratory (LLNL). Figure 1 shows a description of a typical heated experiment. The projectile consisted of a micarta tube with polycarbonate end caps with a 6061-T6 Aluminum flyer plate on the impact surface. As seen in Figure 1, the target includes buffer plates in contact with the high explosive at both the front and rear of the assembly to hold the material in place and sandwich the nichrome heater foils. For non-heated shots, a solid aluminum buffer disk on the front and a Teflon backer disk were used. The explosive was in the form of thin disks with gauge packages inserted between the disks. The manganin piezoresistive foil pressure gauges placed within the explosive sample were "armored" with sheets of Teflon insulation on each side of the gauge. Manganin is a copper-manganese alloy that changes electrical resistance with pressure (i.e. piezoresistive). Also used were PZT Crystal pins to measure the projectile velocity and tilt (planarity of impact). During the experiment, oscilloscopes measure change of voltage as result of resistance change in the gauges which were then converted to pressure using the hysteresis corrected calibration curve published elsewhere [8,9].

From the data of the shock arrival times of the gauge locations, a plot of distance vs. time ("x-t plot") is constructed with the slope of the plotted lines yielding the shock velocities with two lines apparent, a line for the un-reacted state as it reacts and a line representing the detonation velocity. The intersection of these two lines is taken as the "run-distance-to-detonation," which is then plotted on the "Pop-Plot" [7] showing the run-distance-to-detonation as a function of the input pressure in log-log space.

The RX-55-AA formulation had an initial density of 1.79 g/cc at 25°C. Based on an average coefficient of thermal expansion of 66 μm/m°C over most of the temperature range, a density at 150°C was calculated to be 1.73 g/cc assuming it was an isotropic material.

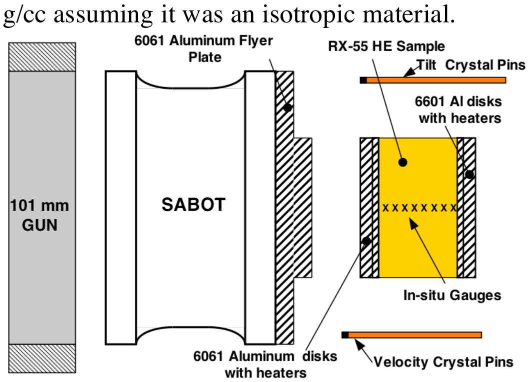

FIGURE 1. Typical description of a shock initiation experiment.

REACTIVE FLOW MODELING

The Ignition and Growth reactive flow model [10] uses two Jones-Wilkins-Lee (JWL) equations of state, in the form:

$$p = Ae^{-R_1 V} + Be^{-R_2 V} + \omega C_V T/V \qquad (1)$$

where p is pressure, V is relative volume, T is temperature, ω is the Gruneisen coefficient, C_V is the average heat capacity, and A, B, R_1 and R_2 are constants. Table 1 contains the equation of state and reaction rate parameters for LLM-105 at 150˚C. The reaction rate equation is:

$$dF/dt = \underbrace{I(1-F)^b(\rho/\rho_0 - 1 - a)^x}_{0<F<F_{Ig\max}} +$$

$$\underbrace{G_1(1-F)^c F^d p^y}_{0<F<F_{G_1\max}} + \underbrace{G_2(1-F)^e F^g p^z}_{F_{G_2\min}<F<1} \qquad (2)$$

where F is the fraction reacted, t is time in μs, ρ is the current density, ρ_0 is the initial density (based on thermal expansion data), p is pressure in Mbars, and I, G_1, G_2, a, b, c, d, e, g, x, y, and z are constants. For LLM-105 at ambient temperature, the only parameter changes are: the initial density (1.79 g/cm^3); unreacted B=-0.05031 Mbar; and G_1=7.0 Mbar^{-1}μs^{-1} [2]. Table 2 details the Gruneisen parameters used.

Table 1. Ignition and Growth modeling parameters.

MATERIAL PARAMETERS	
Shear Modulus=0.0354 Mbar	Yield Strength=0.002 Mbar
T_0 = 423ºK	ρ_0=1.73 g/cm^3 at 150°C
REACTION RATES	
a=0.11	x=7.0
b=0.667	y=1.0
c=0.667	z=3.0
d=0.667	F_{igmax}=0.02
e=0.667	F_{G1max}=0.5
g=0.667	F_{G2min} =0.0
I=1.24 x 10^6 μs^{-1}	G_1=14.0 Mbar^{-1}μs^{-1}
-	G_2=2080 Mbar^{-3}μs^{-1}

Table 2. Gruneisen parameters for inert materials.

INERT	ρ_0 (g/cc)	C (km/s)	S_1	S_2	S_3	γ_0	a
6061-T6 Al	2.703	5.24	1.4	0.0	0.0	1.97	0.48
Teflon	2.15	1.68	1.123	3.98	-5.8	0.59	0.0

Table 3. Summary of RX-55-AA gun experiments.

SHOT	TEMP	IMPACT VELOCITY	INPUT PRESSURE	RUN TO DET
4709	150°C	0.565 km/s	2.2 GPa	-
4710	150°C	0.829 km/s	3.7 GPa	9.8 mm
4711	150°C	1.099 km/s	5.1 GPa	4.1 mm
4712	25°C	1.012 km/s	4.6 GPa	7.5 mm
4713	25°C	1.220 km/s	6.0 GPa	4.6 mm

RESULTS/DISCUSSION

Table 3 contains the experimental flyer velocities, impact pressures, and run distances to detonation for the RX-55 shots performed at 25°C and 150°C.

The resulting data points are plotted on the Pop-plot as shown in Figure 2. The data at 25°C show a good fit to the previous RX-55-AB formulation and the 150°C points show a slight increase in sensitivity as expected.

A comparison of the in-situ gauge records (solid lines) with the Ignition and Growth modeling results (dashed lines) are shown in Figures 2-5 and show a reasonable fit. The modeling shows a growth to detonation sooner than the experimental records.

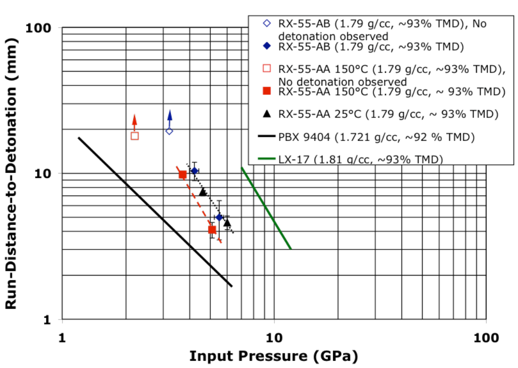

FIGURE 2. Pop-Plot comparing the data from this work with that of previous experiments.

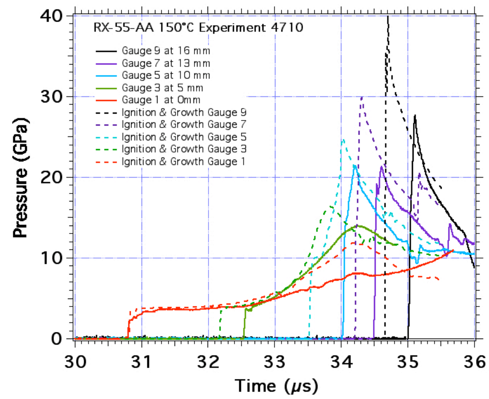

FIGURE 3. Experimental and calculated pressure histories for Experiment 4710.

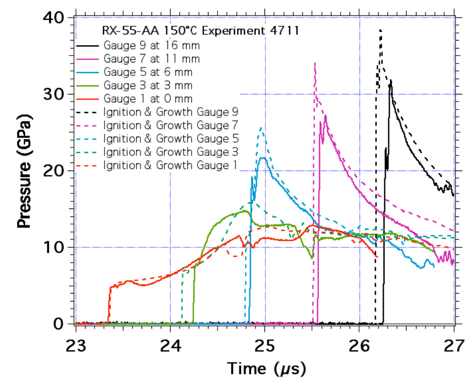

FIGURE 4. Experimental and calculated pressure histories for Experiment 4711.

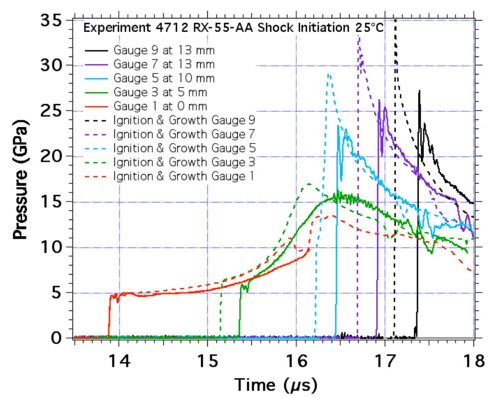

FIGURE 5. Experimental and calculated pressure histories for Experiment 4712.

SUMMARY

Shock initiation experiments on the explosive RX-55-AA (95% LLM-105, 5% Viton by weight) were performed at 25°C and 150°C to obtain in-situ pressure gauge data and Ignition and Growth modeling parameters. The run-distance-to-detonation points on the Pop-plot for these experiments showed agreement with previously published data and Ignition and Growth modeling parameters were obtained with a reasonable fit to the experimental data. Further work is needed to expand this data set and also incorporate improvements of the Ignition and Growth modeling parameters to this expanded data set.

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REFERENCES

1. Pagoria, P F. 2005. Synthesis and scale-up of 2,6-diamino- 3,5-dinitropyrazine-1-oxide (LLM-105), manuscript submitted for publication to Propellants, Explosives, Pyrotechnics.
2. Tarver, Craig, M., Urtiew, Paul, A., and Tran, Tri D., “Sensitivity of 2,6-Diamino-3,5-Dynitropyrazine-1-Oxide,” *Energetic Materials*, 23, pp. 183-203, 2005.
3. Cutting, J. L., H. H. Chau, R. I. Hodgin, D. M. Hoffman, F. Garcia, R. S. Lee, E. McGuire, et al. 1998. Eleventh International Detonation Symposium, Aspen, CO: Office of Naval Research ONR 33300-5, pp. 828–835.
4. Tran, T. D., P. F. Pagoria, D. M. Hoffman, B. Cunningham, R. L. Simpson, R. S. Lee, and J. L. Cutting. 2002. Small-scale safety and performance characterization of new plastic bonded explosives containing LLM-105. Twelfth International Detonation Symposium, San Diego: CA, in press.
5. Lee, K., J. Kennedy, L. Hill, T. Spontarelli, J. Stine, and G. Kerley. 1998. Eleventh International Detonation Symposium, Aspen, CO: Office of Naval Research ONR 33300-5, pp. 362–370.
6. Tarver, C. M. and T. D. Tran. 2004. Combustion and Flame, 137: 50–62.
7. Forbes, J. W., C. M. Tarver, P. A. Urtiew, and F. Garcia. 1998. Eleventh International Detonation Symposium, Aspen, CO: Office of Naval Research ONR 33300-5, pp. 145–152.
8. LASL Explosive Property Data, Terry R. Gibbs and Alphonse Popolato, Editors, University of California Press, pp. 353-358, 1980.
9. Vantine, H.C., Erickson, L.M. and Janzen, J., "Hysteresis-Corrected Calibration of Manganin under Shock Loading", J. Appl. Phys., **51** (4), April 1980.
10. Vantine H., Chan J., Erickson L. M., Janzen J., Lee R. and Weingart R. C., "Precision Stress Measurements in Severe Shock-Wave Environments with Low Impedance Manganin Gauges," Rev. Sci. Instr., **51**. pp. 116-122 (1980).
11. Tarver, C. M., Hallquist, J. O., and Erikson, L. M., “Modeling Short Pulse Duration Shock Initiation of Solid Explosives,” *Eighth Symposium (International) on Detonation*, Naval Surface Weapons Center NSWC MP86-194, Albuquerque, NM, 1985, pp. 951-961.